Inchworm Deep Drilling System (IDDS)

Honeybee Robotics , Ltd.

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ASTEP PI Meeting

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Overview of Subsurface Systems

Honeybee Introduction

- For more than 10 years, Honeybee has been committed to developing robust, automated solutions for subsurface sample acquisition & sample manipulation
- Strong focus on simple, elegant mechanical systems that feature custom mechanisms, tooling and sometimes exotic materials (e.g., drill bits, sliding interfaces)
- Draw on extensive automation experience from industrial projects – "make-before-break", "positive capture & transfer", "task-oriented solution" are part of the Honeybee vernacular
- Continue to work closely with those in the science and engineering communities (NASA and beyond) to develop the best overall solution to the task at hand

Subsurface Systems

Mole

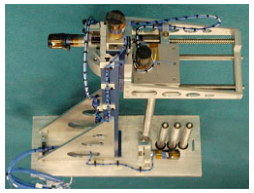
Funding: GSFC

Start Date: Sep. 1993
Duration: 12.5 mos.

Champollion SATM

Funding: JPL

Start Date: Jan. 1998
Duration: 36 mos.



Mars Deep Drill

Funding: PIDDP, JPL

Start Date: Apr. 2000
Duration: 44 mos.

Large Volume Sampler

Funding: NASA SBIR
Ph. I & II

Start Date: Feb. 2001
Duration: 30 mos.

IDDS

Funding: ASTEP, PIDDP

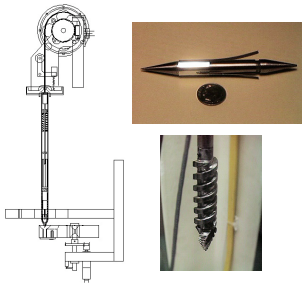
Start Date: Mar. 2003
Duration: 41 mos.

1993 1996 1998 1999 2000 2001 2002 2003

Initial concepts for IDDS, Mini-Corer, Mini-Penetrator, & Pile-Driver

Funding: NASA SBIR Ph. I

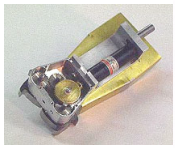
Start Date: Jan. 1996
Duration: 5 mos.



Mini-Corer

Funding: JPL

Start Date: May 1998
Duration: 33 mos.



TGSS

Funding: NASA SBIR
Ph. I & II

Start Date: Dec. 1999
Duration: 6 mos.

RAT

Funding: JPL

Start Date: Dec. 2000
Duration: 28 mos.

Subsurface Telescoping Sampling System

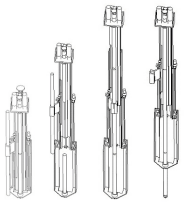
Funding: ASTID

Start Date: Aug. 2002
Duration: 24 mos.

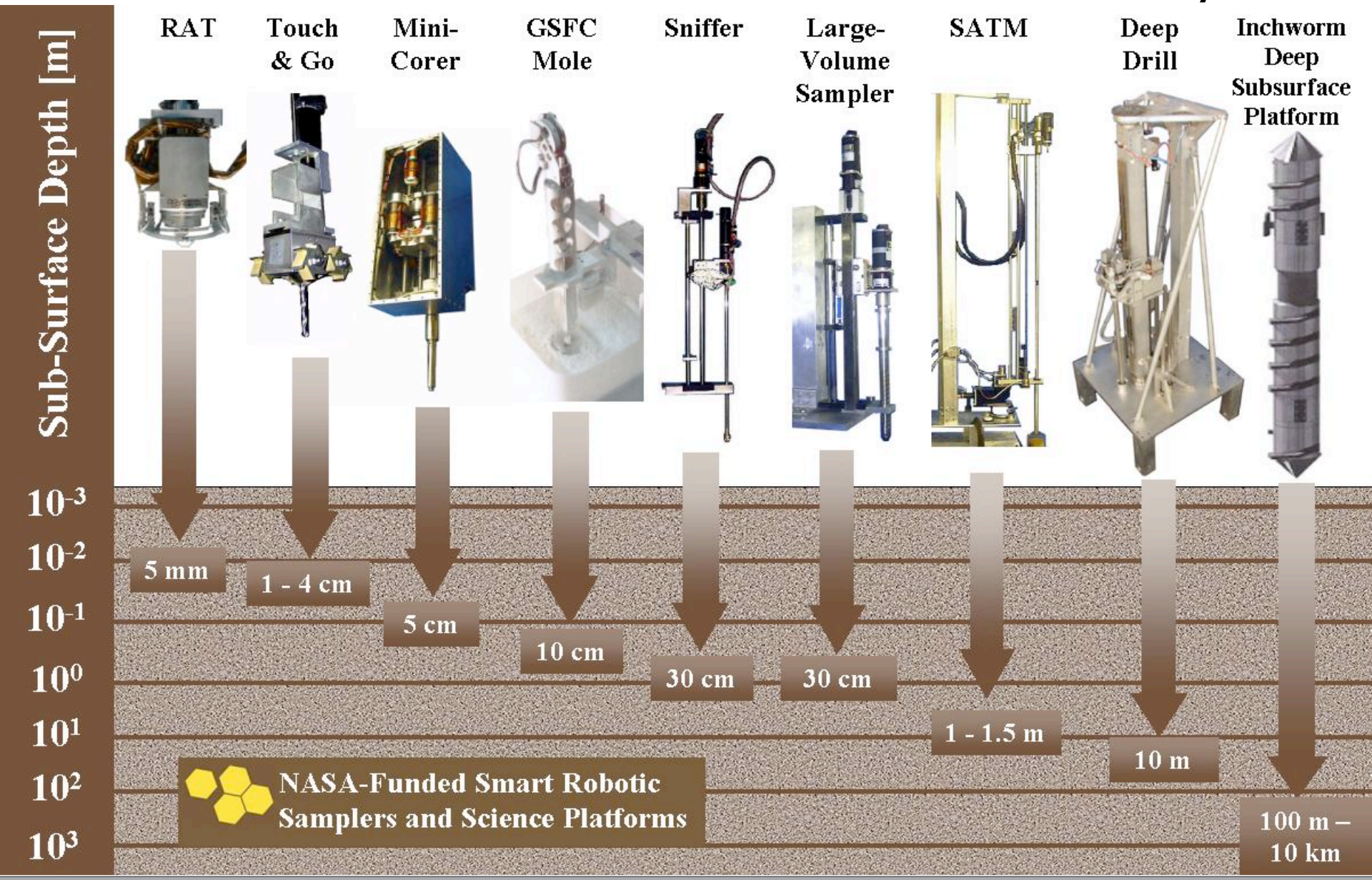
Ultrasonic Drill

Funding: ASTEP

Start Date: Dec. 2003
Duration: 36 mos.



Subsurface Systems



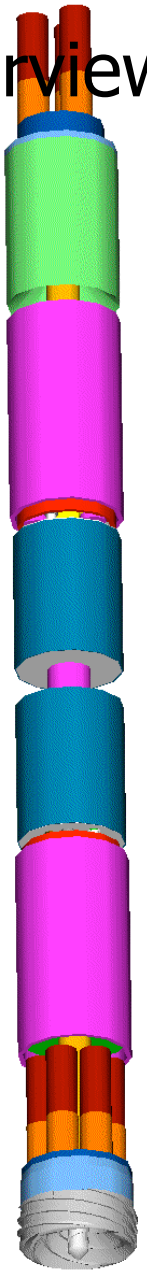
Program Overview

Inch-Worm Style Drill

- Funded under separate NASA ROSS programs
  (CY03 through mid-CY06)
- ASTEP focus on drill bit design and field demonstration
- PIDDP focus on mobility and technology development
- Current Status: Preliminary Design phase
- 2006 milestone: drill >20-m in Bedford limestone
- Internal Goals:
- Achieve depths greater than 100-m (1-km)
- Accommodate borehole science and sample acquisition
- Fully autonomous operation

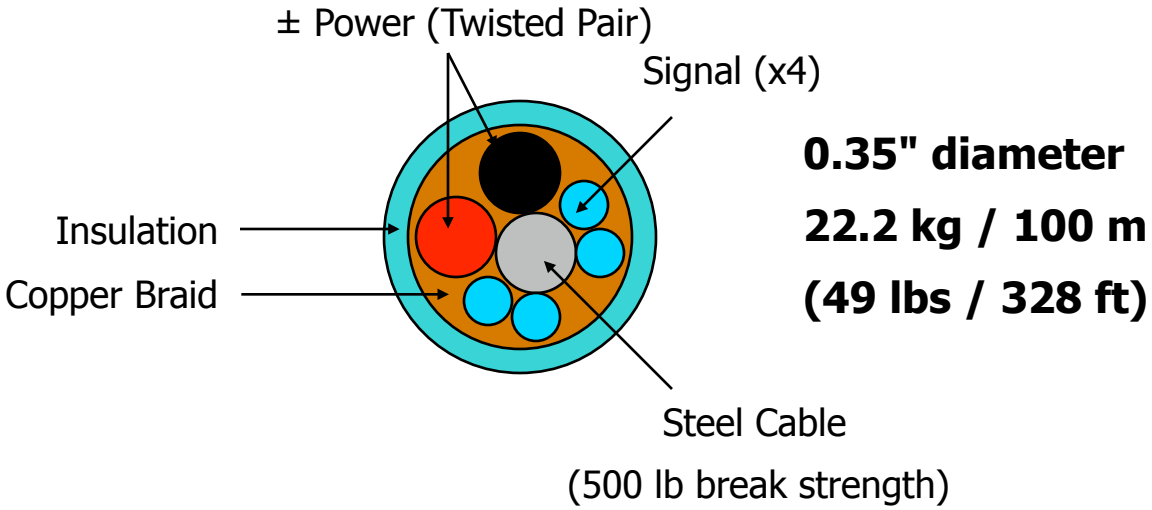
IDDS Overview

- Body: 10.8 cm (4.25 in)
- Hole OD: 11.4 cm (4.5 in)
- Max cont power consumption: 900 W
- Inner drill bit:
  - 3 motors
  - 300 W
  - 40 to 60 rpm (running speed)
  - 250 in lbs torque
- Outer drill bit:
  - 6 motors
  - 600 W
  - ~20 rpm
  - 1000 in lbs torque



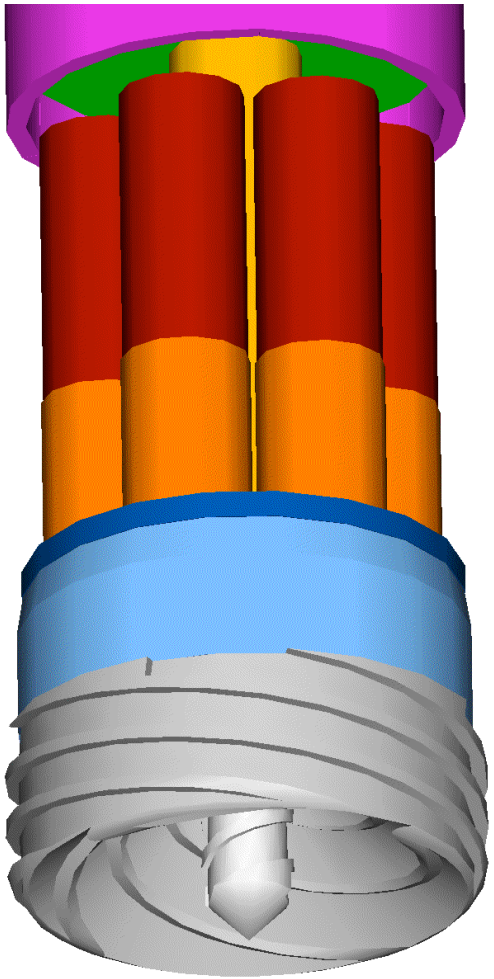
Power / Motors Overview

- Power source (electric motors)
- 23 motors: Drill, Thrusters, Feet, and Bucket
- Drill [9]: 6 outer, 3 inner
- Thrusters [6]: 3 movement, 3 expand/contract
- Feet [6]: 3 front, 3 back
- Bucket [2]: 1 open, 1 eject
- Tether Design:



Drill Bit Overview

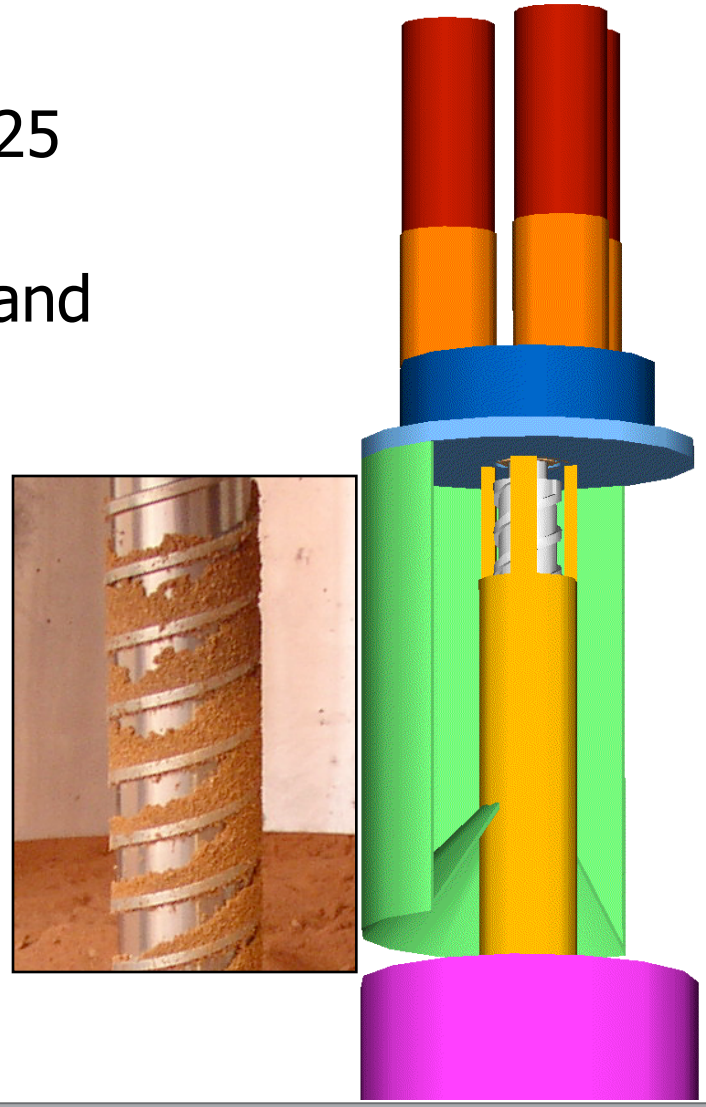
- 2 Counter-rotating bits (1 inner, 1 outer)
- Specifications:
- Inner: 3 motors, 300 W,
  40-60 rpm, 250 in lbs
- Outer: 6 motors, 600 W,
  ~20 rpm, 1000 in lbs
- Integrated Sample Acquisition (optional)
- Extra science & Increase drill efficiency
- Thrust is less if not cutting at center where angular drill velocity is zero
- Extra science



Chip Removal

- Chips get deposited in bucket at tail
- For every inch of drilling into rock, 3.25 inches of debris generated
- (function of drill and bucket diameter and rock expansion when broken down)

- When bucket reaches top of launch tube it is opened and debris is positively ejected



Mobility

Both legs out

Body fixed w.r.t. ground

Drill turns on

Head and bucket (fixed to spine) move down

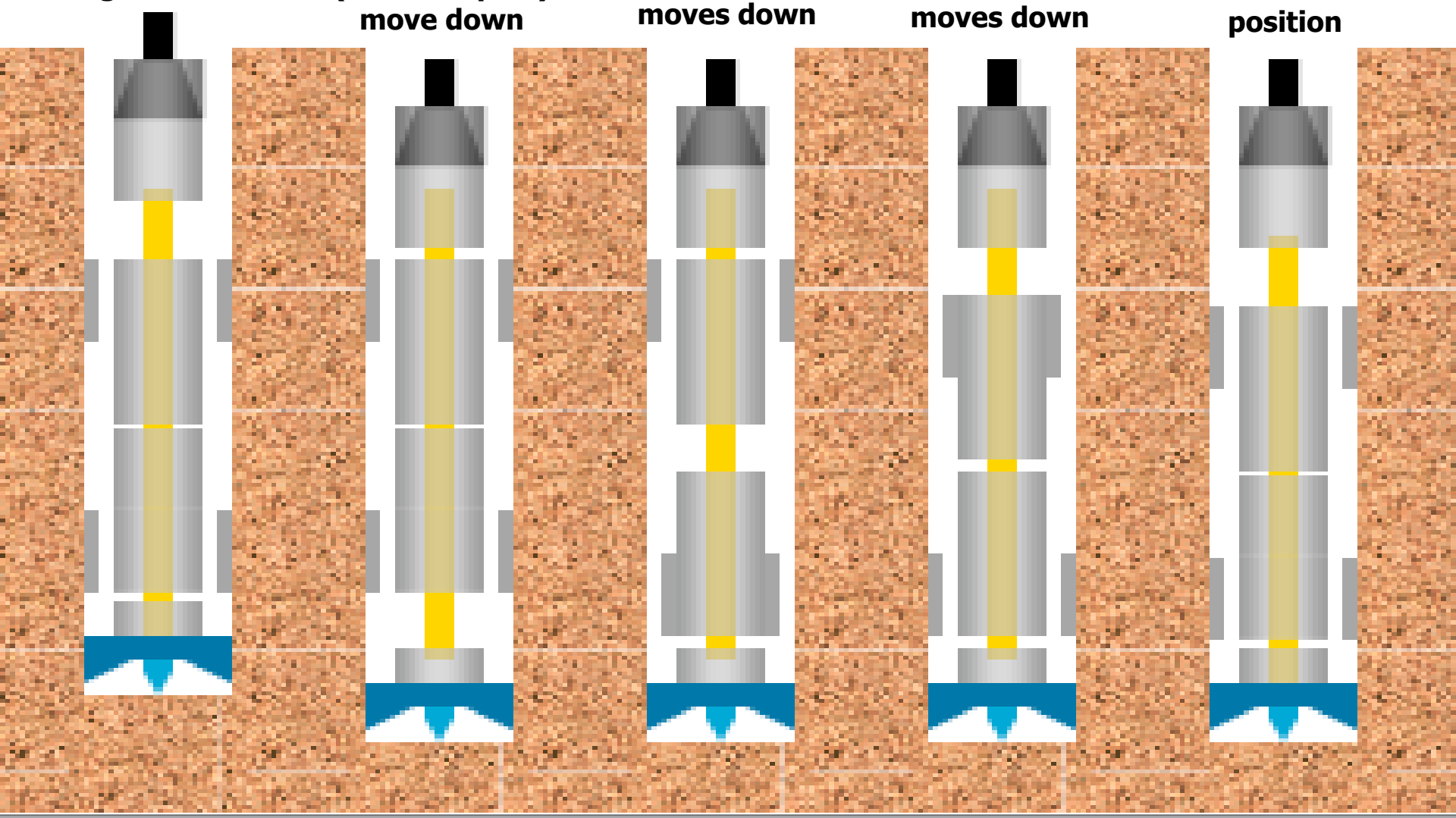
Front legs retract and segment moves down

Front legs expand

Rear legs retract and segment moves down

Rear legs expand

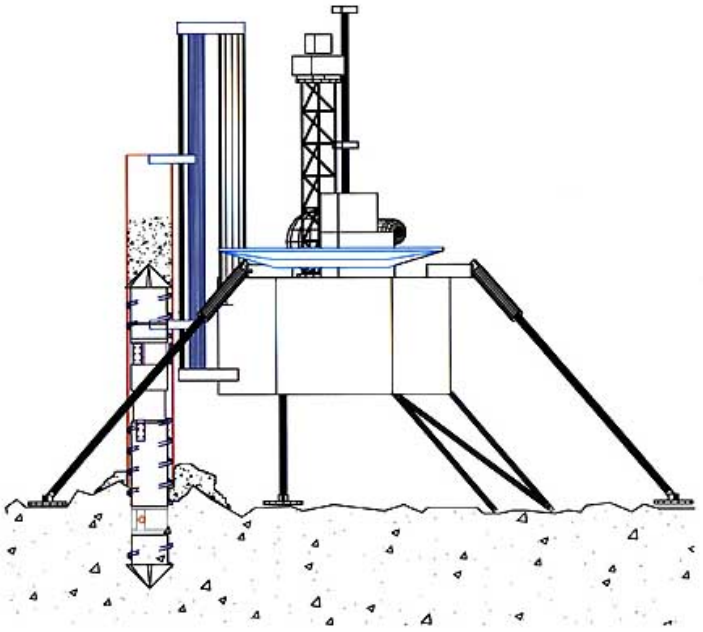
Same as initial position

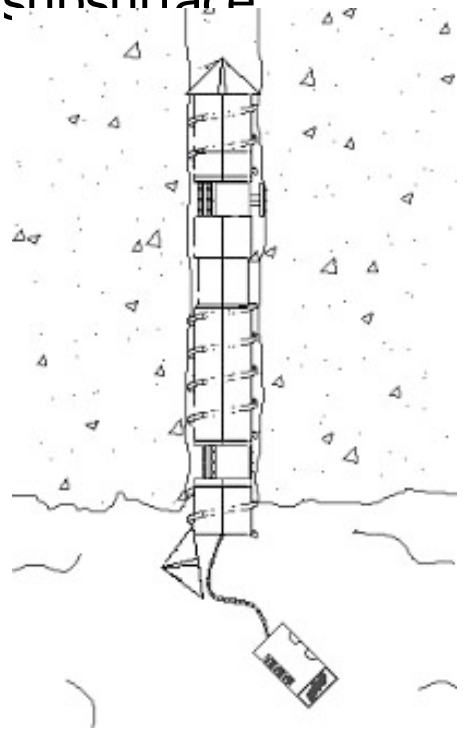


Future

Untethered Autonomous Deep Exploration

- "Launch tube" deployment from lander or mobile platform
- Employs inchworm motion for movement in borehole
- Tethered and Untethered concepts are being explored
- Future untethered designs to accommodate Stirling Power System
- Targets include ice environments (Europa) and Mars subsurface





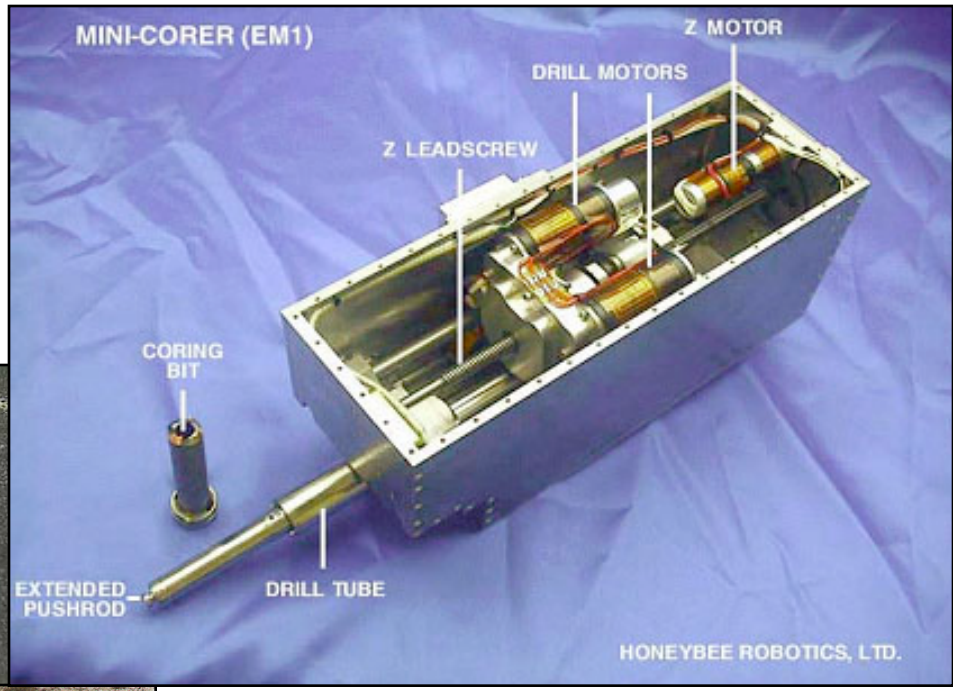
Early concept depictions

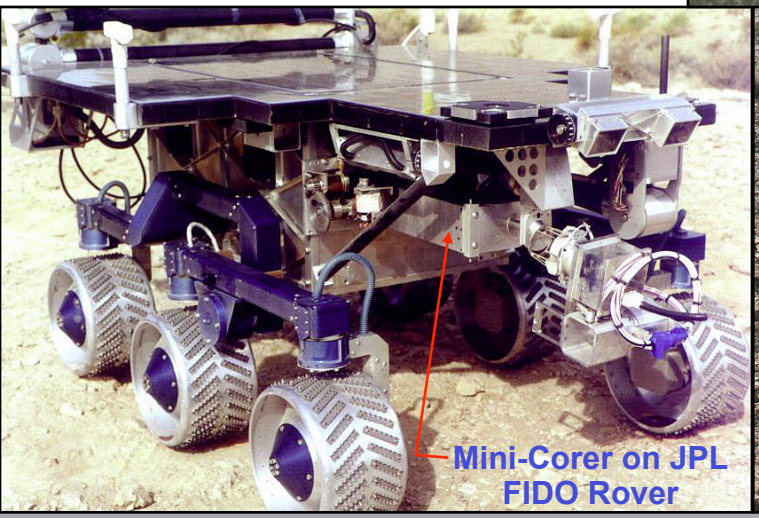
Related Work

Mini-Corer

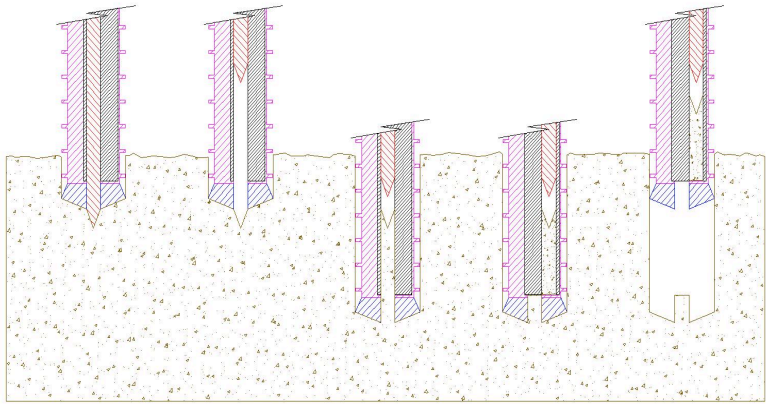
2003 Mars Sample Return (MSR) Mission "Mini-Corer" Rock & Soil Sampling Device

- Obtain fresh rock cores up to 5-cm deep
- 50-mm long x 8-mm OD rock cores
- 6-min, 30-lbf and 3-Whr per core in basalt
- Stand-alone operation
- Significant fault prevention & recovery algorithm work
- TRL-6 – field tested on FIDO in Mojave Desert
- MER replaced MSR in 2000





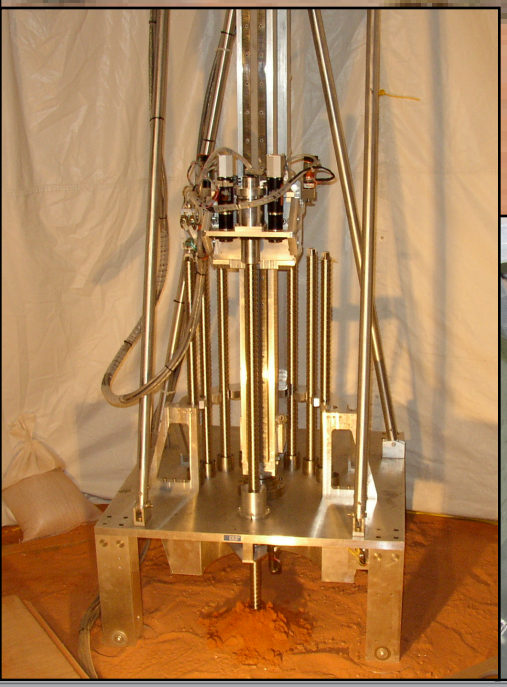
Patented Core Acquisition and Break-off Method

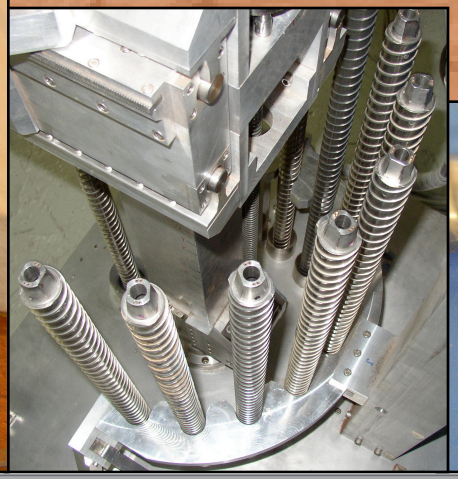


Honeybee Deep Drilling

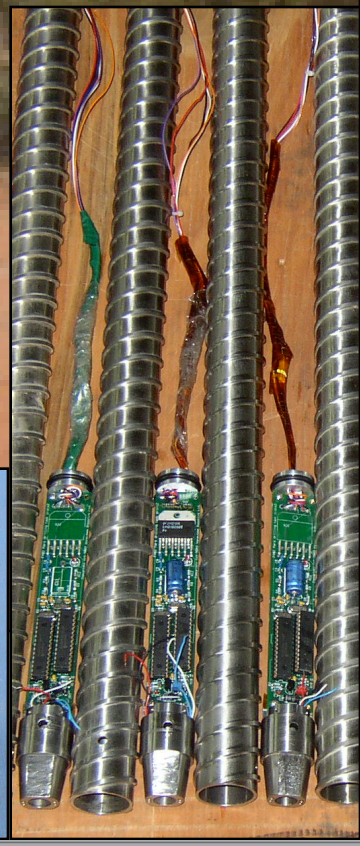
10-m Class Auger Style Drill (Mars Deep Drill)

- Work began in 2000
- Depth Requirement: >10 m
- Demonstrated Capability: 8.3 m
- Designed to obtain solid rock cores and unconsolidated samples
- Segmented Drill String – Designed to accommodate bore-hole instruments





High Strength Connections



Mars Deep Drill – Test bed

- Test bed design currently holds 10 drill string segments (each 1-m long & 1.375 in. OD)
- Indexing capability enables automated access to drill string cache and sample storage/handoff mechanisms
- Z-axis drive: >1-m stroke, 600 lbf. max. cap.
- Dual auger drive motors provide 130 in-lb of torque (300 RPM max.)
- Field testing in sandstone yielded on average 210 W-hr & 6.5 hours per meter
- Drill string segments feature electrical power and data connections for borehole science instrumentation and sample acquisition device

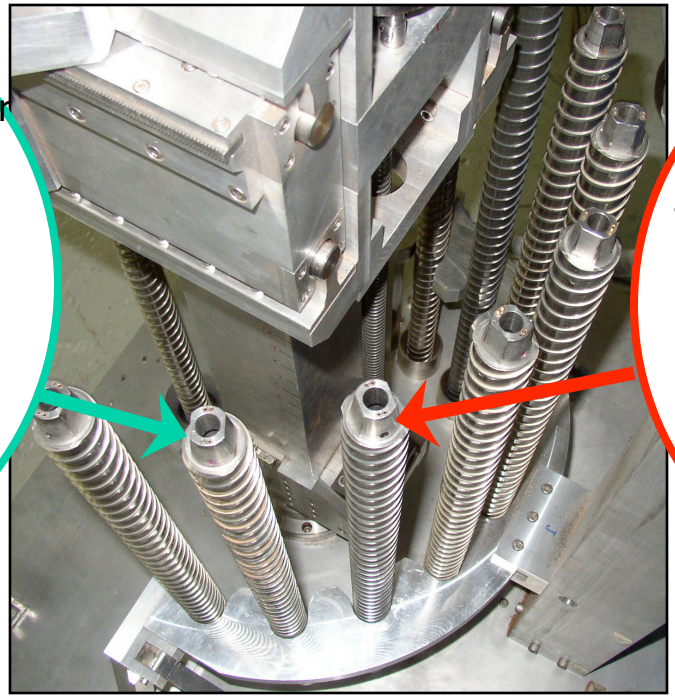
Honeybee Deep Drilling

Mars Deep Drill – Borehole Science Platform

- Honeybee's Mars Deep Drill serves as a platform for borehole science
- Drill string segments feature large volume for instrument packaging
- Individual instrumented drill segments selectively chosen based on site specifics

"Drill-Integrated He^3 Neutron Spectrometer to Characterize Distribution of Subsurface Water and Hydrated Minerals"

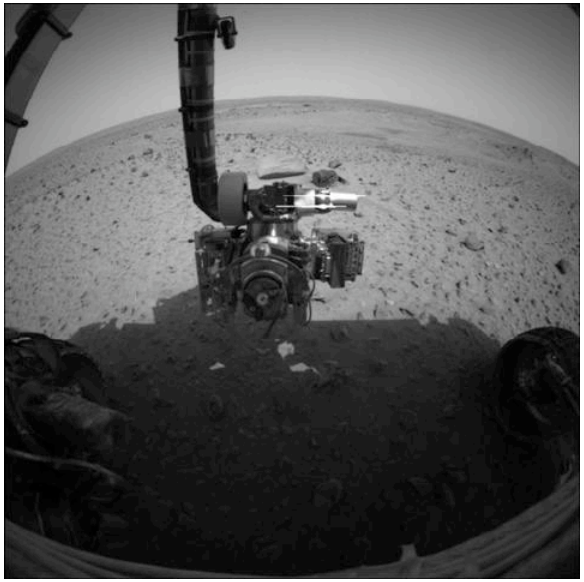
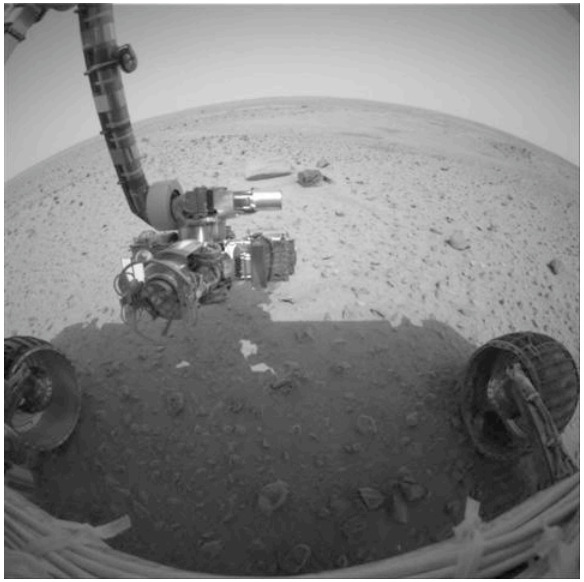
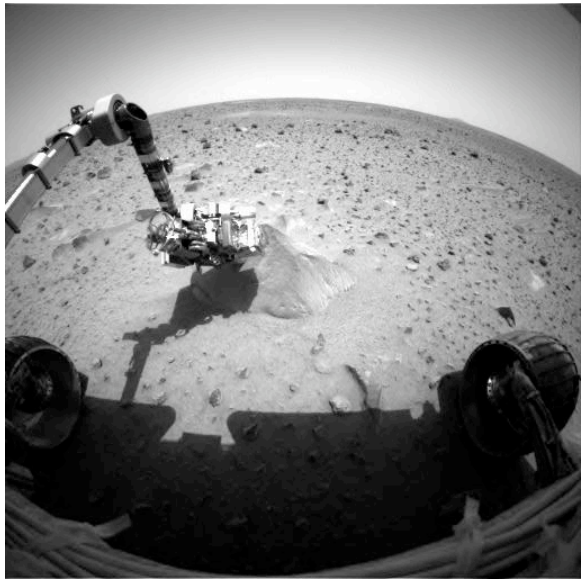
Team:
Honeybee Robotics &
Los Alamos National Laboratory



"Mars Borehole Infrared Spectrometer"

Team:
Jet Propulsion Laboratory, Honeybee Robotics &
Ion Optics

Other borehole instrumentation collaborations pending

Questions?